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Parameter choice optimization of ventilating air cleaning equipment while designing and constructing industrial buildings

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Abstract

Functioning of industrial buildings is impossible without correctly organized ventilation system. Its work both regulates heat moist mode and the required indoor air purity that is cleaned with the help of air cleaning equipment. To make decision to construct the required air cleaning equipment at the enterprise a comparative economic assessment of various options is likely to be used, but due to the uncertainty factor, the economic analysis does not always allow to give a definite answer. Therefore, it is worthwhile to give additional parameters and to solve a problem of multicriteria optimization to get the best results. The choice of the best variant is supposed to be carried out using Harrington's desirability function. The conducted multicriteria analysis allowed to reveal optimum characteristics of air cleaning equipment, based on the required purification air degree, the geometrical sizes of the equipment and profit ratio while introducing any particular device.

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*Keywords:*ventilating emissions; air cleaning equipment; purification efficiency; device dimensions; economic efficiency; profit ratio; optimum criteria.

1. Introduction

The problems of atmospheric air protection are an integral part of aspects defining environmental conditions [1]. Ventilating emissions of industrial enterprises containing firm or liquid weighed particles pollute the atmosphere heavily. Technological processes and equipment development intended for emissions decrease from industrial

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enterprises, that is ventilating emissions cleaning from aerosols are an integral part of environmental protection measures.

Nomenclature

η	cleaning efficiency
L	sedimentation element length
D (D_e)	tube diameter (channels equivalent diameter)
Δp	aerodynamic resistance
t	time from the receiving result moment (expenses) until comparison measured in years
R_t	the results achieved on t calculation step
$З_t$	the expenses carried out on t step
T	calculation time period
z_i	the coded value of the i-th kind values of an indicator representing non numerical values
x_i	value of the i-th kind informative indicator
x_{i0} and x_{i1}	area borders of "satisfactory" in an initial scale.

On the other hand, functioning of industrial buildings is impossible without correctly organized ventilation system. Its work both regulates heat moist mode and the required indoor air purity that is cleaned with the help of air cleaning equipment. [2-4].

To increase the efficiency of ventilating system work it is worthwile to provide air cleaning equipment especially from high-disperse aerosol particles with sizes less than 1 micron being most harmful for human body [5-9].Utilization efficiency of ventilating emissions cleaning equipment from submicronic sizes aerosols is defined mainly by their cost, convenience and profitability of installation and operation, as well as the possibility to return the trapped production raw materials [2,8].

When using ventilating emissions cleaning equipment which is based on high-disperse particles sedimentation in thin tubes and slot-hole channels [10-13] air purification degree, geometrical characteristics and aerodynamic resistance (loss of pressure) of the device are the parameters characterizing utilization efficiency of equipment:

$$\eta = f(L/D; \Delta p) \tag{1}$$

Researches have shown [6-9] that it is possible to achieve given efficiency value using a combination of (L/D; Δp). Values in the range $\eta \geq 90\%$.are of great interest. For identical value of cleaning efficiency, increase in L/D value leads to the losses pressure reduction of Δp. To find an optimum combination of L/D values and Δp, giving the maximum effect is the aim of this paper.

2. Comparative economic assessment of device modifications

In the market economy conditions the most important factor of a firm enterprise development is the efficiency of investment activity which is characterized by the efficiency increase of business and operations of the enterprise due to the cleaning equipment installation [14]. While introducing cleaning equipment it's worthwhile to give an economic assessment of the proposed solutions. For this purpose it is necessary to carry out the comparative economic analysis of the device modifications characterized by a pair of values (L/D; Δp).

Assessment methods of financial and economic efficiency of the project taking into account time factor assume expenses and income matching at different time to a basic timepoint, in our case, to project implementation date.

Reduction coefficients calculation is carried out on the basis of a rate or discount rate (E). As approximate value of the discount rate the existing average interest rates for long-term rates of refinancing established by the Central Bank of the Russian Federation can be used. Reduction of expenses sizes and their results is carried out by their multiplication by the discounting coefficient (α_t) determined for constant norm of discount E by a formula:

$$\alpha_t = 1/(1+E)^t \tag{2}$$

For implementation of the comparative economic analysis of different variants it is necessary to estimate the possible income and expenses arising at project implementation. The analysis was made for installation with a productivity of 10000 m^3/hour and initial concentration of dioctylphthalate of 100 mg/m^3.

The economic efficiency assessment of the investment project is made with use of profit ratio (profitability) of investments of *BCR*.The profit ratio (*BCR*) is the ratio of the income sums to the given expenses value:

$$BCR = \frac{\sum_{t=0}^{T} R_t \times \alpha_t}{\sum_{t=0}^{T} \text{З}_t \times \alpha_t} \tag{3}$$

The calculation time period is accepted according to the terms of project implementation. In our case *T* is accepted as being equal to the average fan utilization time– 12 years. The norm of discount is 12%.

If *BCR*>1, the project is effective, if *BCR*<1, then the project is inefficient. Profit ratios of values (*L/D; Δp*) with cleaning coefficient of 90-98% are presented in table 1.

Table 1.Profit ratio *BCR.*

Δp, Pa	Value *L/D*					
	175	200	225	250	275	300
800					2,04	2,07
1000		η< 90%		1,81	1,80	1,80
1200				1,62	1,62	1,60
1400			1,45	1,46	1,46	1,46
1600			1,31	1,33	1,33	1,30
1800		1,20	1,21	1,22	1,23	1,20
2000		1,11	1,12	1,13	1,13	1,11
2200	1,03	1,05	1,05	1,06	1,05	1,04

* Box colors correlate to the cleaning efficiency,%

97-98	95-96	93-94	91-92	90

The conducted economic analysis of the equipment modifications characterized by values (*L/D; Δp*) has shown the efficiency of all considered variants. The more *L/D* and less *Δp* values are, the higher profit ratio is. However, any indicators used for an economic project assessment can't show all the features of the investment project. The uncertainty factor which is present in the economic analysis connected with an expenses value assessment determined by the capital investments volume depending on the materials cost, the equipment and installation, utilization expenses that are influenced by electricity payment: income values depending on the cost of the material returned into production and emission cost should be taken into account.

Sensitivity chart of *BCR* value for *L/D*=250, *Δp* = 1200 Pa from significant parameters change is given in Figure 1: costs of metal, cost of electric power, cost of raw materials, a payment for polluting substance emissions.

The analysis of the chart shows that most strongly BCR change value is influenced by the cost of the separated material (in our case dioctylphthalate), i.e. in case of raw materials price increase or the use of more expensive substance with similar physical properties, economic indicator value can increase considerably and thus the group of the acceptable values (L/D; Δp) can be changed. The payment change of polluting substance emissions impacts less strongly on BCR. Thus, cost change of electricity and metal cost can also influence the investment project prospects.

The change of every specified factor leads to the shift and parameters adjustment characterizing investment project efficiency. Therefore, for improving assessment quality of a final version choice it is necessary to introduce the additional limiting factors and to use multicriteria methods of decision-making [15]

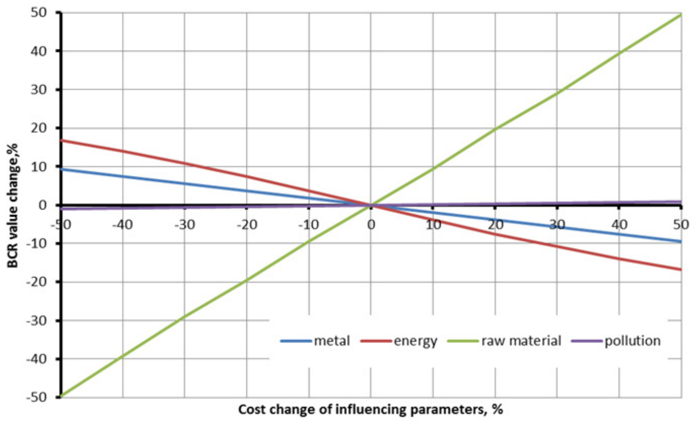

Fig. 1. Sensitivity of BCR value from the influencing parameters.

3. Use of multicriteria optimization for justification of cleaning equipment characteristics

In case when comparative economic analysis doesn't allow to reveal unambiguous values of optimum characteristics of dust cleaning equipment, it is worthwhile to introduce additional criteria and to solve a problem of multicriteria optimization.

For the solution of multicriteria tasks various methods of definition of generalized optimality indicator are used. In case of multidimensional criteria the optimization can be conducted using of Harrington's desirability function *d(x)*. It has resulted from observations over real solutions made by the researchers and possesses continuity, monotony and smoothness properties. Significant parameters are recalculated into numerical values, and then the general indicator is defined [15]. Harrington's scale establishes correlation between linguistic desirability assessments of indicator values x and numerical intervals *d(x)* (tab. 2):

Table 2. Numerical intervals of Harrington's scale

Linguisticassessments	Intervals of desirability function values $d(x)$
Excellent	1,00-0,80
Good	0,80-0,63
Satisfactory	0,63-0,37
Bad	0,37-0,20
Poor	0,20-0,00

Three Harrington's scales "bad", "satisfactory", "good" are usually taken into account. In this case the area corresponding to level "satisfactory", extends from 0,37 to 0,69, and areas "bad" and "good" are characterized by intervals [0,00; 0,37 [and]0,69; 1,00], respectively.

Analytically, for monotonous criteria on preferences, Harrington's desirability function is set by the following formula:

$$\begin{cases} d_i = d(z_i) = \exp(-\exp(-z_i)) \\ z_i = (x_i - x_{i0})/(x_{i1} - x_{i0}) \end{cases} \tag{4}$$

Introduction of a desirability scale allows to reduce the initial multicriteria problem of decision-making with non numerical criteria to a multicriteria task with the criteria measured by the same scale, therefore the following stage is convolution of definite desirability functions in the generalized desirability criterion D_i.

$$f\left(d_1, d_2, \dots . d_n\right) = \mathrm{D}_i = \sqrt[n]{\prod_{i=1}^{n} d_i} \tag{5}$$

Thus, the problem of criterion optimization ("the effect of maximum") mathematically will be as follows:

$$\begin{cases} \sqrt[n]{\prod_{i=1}^{n} d_i} \to \max \\ 0,368 \le d_i \le 0,692, i = 1, n \\ d_i = d(z_i) = \exp(-\exp(-z_i)) \\ z_i = z_i(x) = (x_i - x_{i\min}) / (x_{i\max} - x_{i\min}) \end{cases} \tag{6}$$

To find an optimum combination of geometrical dimensions of collecting element, aerodynamic resistance of the device and its cleaning effectiveness ratio it is worthwhile to reveal the generalized desirability criterion using the following criteria:

- cleaning efficiency: range of criterion change at an interval $\eta \in [90; 98]$;
- geometrical dimensions of collecting elements: $L/D \in [175; 300]$;
- profitratio: $BCR \in [1,03; 2,07]$.

According to these indicators various combinations of values are compared (*L/D; Δp*), defining the characteristic of the designed cleaning device. Definite parameters of compared variants corresponding to certain values (*L/D; Δp*), are distributed on effective values intervals of a private indicator scale. Then the indicators corresponding to them are recalculated in marks according to the desirability scale. The received $d_i$value for the *i*-th kind parameter is recalculated into the generalized optimum coefficient.

Generalized optimum criterion values are determined by the following formula and are given in table 3 and are shown in figure 2.

$$D_i = \sqrt[3]{\prod_{i=1}^{3} d_i} \tag{7}$$

Table 3.Optimum criterion value.

	Ratio *L/D*					
Δp, Pa	175	200	225	250	275	300
800					0,481	0,472
1000				0,490	0,501	0,471
1200				0,511	0,501	0,483
1400			0,479	0,510	0,499	0,481
1600			0,481	0,509	0,496	0,473
1800		0,465	0,485	0,507	0,494	0,470
2000		0,471	0,501	0,505	0,489	0,466
2200	0,454	0,477	0,501	0,503	0,486	0,456

The conducted multicriteria analysis allowed to reveal optimum geometrical characteristics of the collecting elements and aerodynamic resistance corresponding to them. According to the calculations the best result is observed at value *L/D*=250 and aerodynamic resistance *Δp* in the range of [1200 Pa; 1400 Pa]. Cleaning efficiency η=92% corresponds to the device parameters.

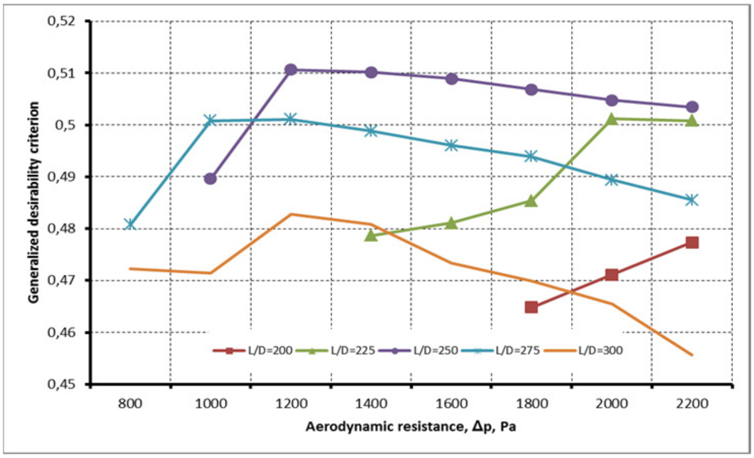

Fig. 2.Values of the generalized optimum criterion.

4. Conclusions

Taking into account that now in industrially developed countries the functioning of industrial enterprises includes technical and organizational measures this or that way directed to the termination or reduction of atmosphere pollution the increase of ventilating systems work efficiency by implementation of cleaning equipment is an up-to-date problem. And obtained economic result is not the only maximum efficiency criterion but demands a combination of such factors as cleaning emissions extent and overall dimensions of the device being used. Thus, the conducted researches allowed to calculate the generalized optimum criterion determining the most significant geometrical parameters of air cleaning equipment and their optimum operating mode as a part of ventilating system.

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